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Monitored this issue:

Small nuclear reactors: a history of failure

Jim Green, Friends of the Earth Australia

Small modular reactors (SMRs) are defined as reactors with a capacity of 300 megawatts (MW) or less. The term 'modular' refers to serial factory production of reactor components, which could drive down costs. By that definition, no SMRs have ever been built, none are being built now, and in all likelihood none will ever be built because of the prohibitive economics.

No SMRs have been built, but dozens of small (<300 MW) power reactors have been built in numerous countries, without factory production of reactor components. The history of small reactors is a history of failure. The US Army built and operated eight small reactors beginning in the 1950s, but they proved unreliable and expensive and the program was shut down in 1977. In addition, 17 small civilian reactors were built in the US in the 1950s and 1960s, but all have since shut down.

Twenty-six small Magnox reactors were built in the UK but all have shut down and no more will be built. The only operating Magnox is a mini-Magnox in North Korea: the design was made public at an Atoms for Peace conference and North Korea uses its 5 MW Magnox to produce plutonium for nuclear weapons.

India's operates 14 small pressurised heavy water reactors, each with a capacity of about 200 MW. Prof. M.V. Ramana noted in his 2012 book, 'The Power of Promise: Examining Nuclear Energy in India', that despite a standardised approach to designing, constructing, and operating these reactors, many suffered cost overruns and lengthy delays. There are no plans to build more of these small reactors in India.

Elsewhere, the history of small reactors is just as underwhelming. This includes three small reactors in Canada (all shut down), six in France (all shut down), and four in Japan (all shut down).

Prof. Ramana concludes his history of small reactors with this downbeat assessment: "Without exception, small reactors cost too much for the little electricity they produced, the result of both their low output and their poor performance."

Recent history

Just two SMRs are said to be operating -- neither meeting the 'modular' definition of serial factory production of reactor components. The two SMRs -- one each in Russia and China -- exhibit familiar problems of massive cost blowouts and multi-year delays.

The construction cost of Russia's floating nuclear power plant increased six-fold and the OECD's Nuclear Energy Agency estimates that the electricity it produces costs an exorbitant US$200 / megawatt-hour (MWh). The reactor is used to power fossil fuel mining operations in the Arctic.

The other operating SMR (loosely defined) is China's demonstration 210 MW high-temperature gas-cooled reactor (HTGR). The World Nuclear Association states that the cost of the demonstration HTGR was US$6,000 per kilowatt, three times higher than early cost estimates and 2-3 times higher than the cost of China's larger Hualong reactors per kilowatt.

NucNet reported in 2020 that China dropped plans to manufacture 20 HTGRs after levelised cost estimates rose to levels higher than conventional large reactors. Likewise, the World Nuclear Association states that plans for 18 additional HTGRs at the same site as the demonstration HTGR have been "dropped". China's demonstration HTGR demonstrates yet again that the economics of small reactors doesn't stack up.

Three SMRs are under construction – again with the qualification that there's nothing 'modular' about these projects.

Argentina's CAREM reactor has been a disaster. Construction began in 2014 and the National Atomic Energy Commission now hopes to complete the reactor in 2027 -- nearly 50 years after the project was conceived. The cost estimate in 2021 was US$750 million for a reactor with a capacity of just 32 MW. That equates to a wildly uneconomic US$23,400 per kilowatt.

In 2021, China began construction of a 125 MW pressurised water reactor. According to China National Nuclear Corporation, construction costs per kilowatt will be twice the cost of large reactors, and levelised costs will be 50 percent higher than large reactors.

Also in 2021, construction of the 300 MW demonstration lead-cooled BREST fast neutron reactor began in Russia. The cost estimate has more than doubled and no doubt it will continue to climb.

NuScale Power

In 2012, the US Department of Energy (DOE) offered up to US$452 million to cover "the engineering, design, certification and licensing costs for up to two US SMR designs." The two SMR designs that were selected by the DOE for funding were NuScale Power and Generation mPower.

However NuScale recently abandoned its flagship project in Idaho as *RenewEconomy* recently reported. NuScale secured subsidies amounting to around US$4 billion from the US government comprising a US$1.4 billion subsidy from the DOE and an estimated US$30 per megawatt-hour (MWh) subsidy in the Inflation Reduction Act. Despite that government largesse, NuScale didn't come close to securing sufficient funding to get the project off the ground.

NuScale's most recent cost estimates were through the roof: US$9.3 billion for a 462 MW plant comprising six 77 MW reactors. That equates to US$20,100 per kilowatt and a levelised cost of US$89 / MWh. Without the Inflation Reduction Act subsidy of US$30/MWh, the figure would be US$129 / MWh.

NuScale still hopes to build SMRs but the company is burning cash and heading towards bankruptcy.

Generation mPower

Generation mPower -- a collaboration between Babcock & Wilcox and Bechtel -- was the other SMR design prioritised by the US DOE. mPower was to be a 195 MW pressurised light water reactor.

In 2012, the DOE announced that it would subsidise mPower in a five-year cost-share agreement. The DOE's contribution would be capped at US$226 million, of which US$111 million was subsequently paid. The following year, Babcock & Wilcox said it intended to sell a majority stake in the joint venture, but was unable to find a buyer.

In 2014, Babcock & Wilcox announced it was sharply reducing investment in mPower to US$15 million annually, citing the inability "to secure significant additional investors or customer engineering, procurement and construction contracts to provide the financial support necessary to develop and deploy mPower reactors".

The mPower project was abandoned in 2017. The joint venture companies spent more than US$375 million on the project, in addition to the DOE's US$111 million contribution.

Iceberg Research analysts predicted the collapse of NuScale's Idaho project, drawing a furious response from NuScale, and later drew the connections between NuScale and mPower:

"[NuScale's] trajectory bears striking similarities to the B&W mPower project, a joint venture formed in 2010 between Babcock & Wilcox and Bechtel. Like NuScale, mPower was developing a small modular reactor and enjoyed DOE backing. Babcock & Wilcox, mPower's 90%-shareholder, attempted but failed to sell a majority stake in the project. In a similar vein, NuScale's largest shareholder Fluor is actively trying to sell around 30% of its equity interest in NuScale.

"There was eventually a significant reduction in funding for mPower. In March 2017, Bechtel withdrew from the joint venture, pointing to the challenges of securing a site and an investor for the first reactor. This led to the termination of the mPower project and Babcock & Wilcox paid Bechtel $30m as settlement."

NuScale and mPower had everything going for them: large, experienced companies; conventional light-water reactor designs; and generous government subsidies. But they struggled to secure funding other than government subsidies. Needless to say, non-government funding is even more difficult to secure for projects without the backing of large companies; for projects that envisage construction of unconventional reactors (molten salt reactors, fast neutron reactors, etc.); and for projects that haven't secured generous government subsidies.

NuScale's failure is particularly striking given the extent of the government subsidies and given that NuScale had progressed further through the licensing process than other SMR designs (which isn't saying much).

Other SMR failures

Many other plans to build small reactors have been abandoned. In 2013, US company
"The NuScale announcement follows several other setbacks for advanced reactors. Last month, X-Energy, another promising SMR company, announced that it was canceling

Transatomic Power was promising that its 'Waste-Annihi lating Molten-Salt Reactor' would deliver safer nuclear power at half the price of power from conventional, large reactors. By the end of 2018, the company had given up on its 'waste-annihilating' claims, run out of money, and gone bust.

MidAmerican Energy gave up on its plans for SMRs in Iowa in 2013 after failing to secure legislation that would require ratepayers to partially fund construction costs.

In 2018, TerraPower abandoned its plan for a prototype fast neutron reactor in China due to restrictions placed on nuclear trade with China by the Trump administration.

The French government abandoned the planned 100-200 MW ASTRID demonstration fast reactor in 2019.

The US government abandoned consideration of 'integral fast reactors' for plutonium disposition in 2015 and the UK government did the same in in 2019. (Plutonium disposition means destroying weapons-useable plutonium through irradiation, or treating plutonium in such a way as to render it useless in nuclear weapons.)

'Advanced' nuclear is not advancing

Dozens of SMR designs are being promoted -- mostly by start-ups with nothing more than a Powerpoint presentation. Precious few will reach the construction stage and the likelihood of SMRs being built in large numbers is negligible.

Moreover the prospects for the broader 'advanced' or 'Generation IV' nuclear sector are dim. A November 28 article from the pro-nuclear Breakthrough Institute put the failure of NuScale's Idaho project in context:

plans to go public. This week, it was forced to lay off about 100 staff.

"In early 2022, Oklo's first license application was summarily rejected by the Nuclear Regulatory Commission before the agency had

even commenced a technical review of Oklo's Aurora reactor.

"Meanwhile, forthcoming new cost estimates from TerraPower and XEnergy as part of the Department of Energy's Advanced Reactor Deployment Program are likely to reveal substantially higher cost estimates for the deployment of those new reactor technologies as well."

The Breakthrough Institute notes that efforts to commercialise a new generation of advanced nuclear reactors "are simply not on track" and it warns nuclear advocates not to "whistle past this graveyard".

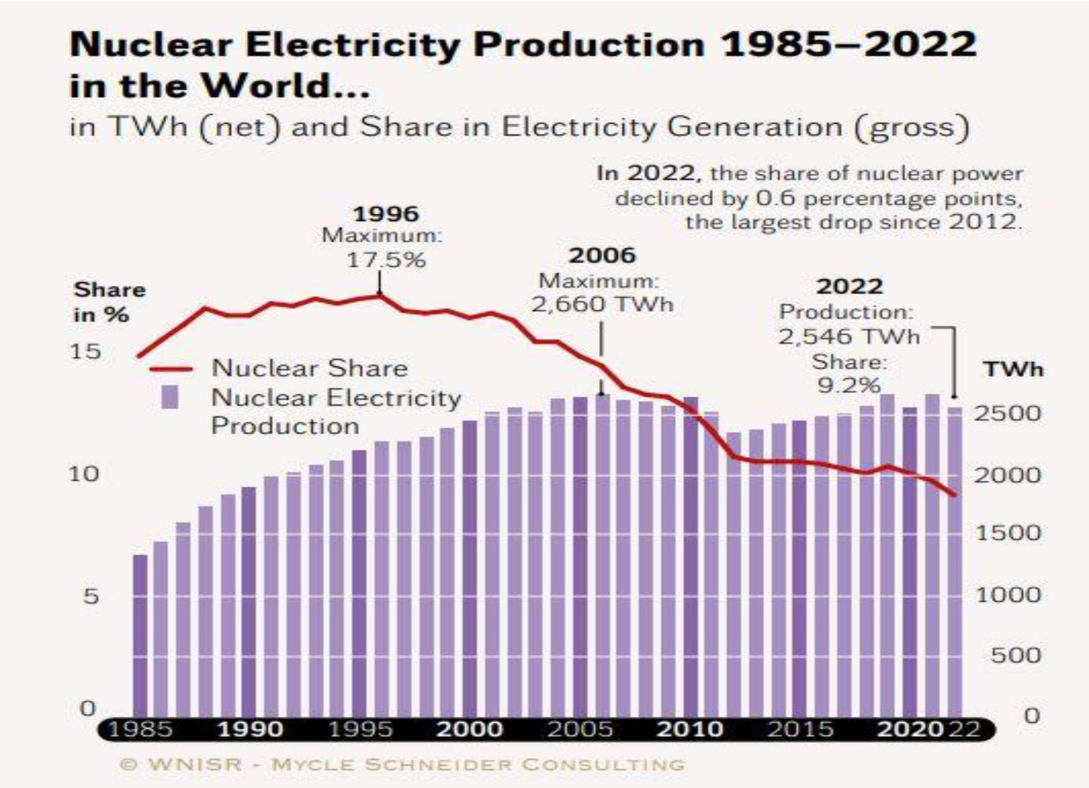
Predictably, the Breakthrough Institute's proposed solutions include vastly greater government subsidies, and a weakening of safety standards and radiation protection standards.

Dr. Jim Green is the [national nuclear campaigner] with Friends of the Earth Australia and author of a detailed [SMR briefing paper] released in June.

World Nuclear Industry Status Report: Nuclear power on the decline worldwide

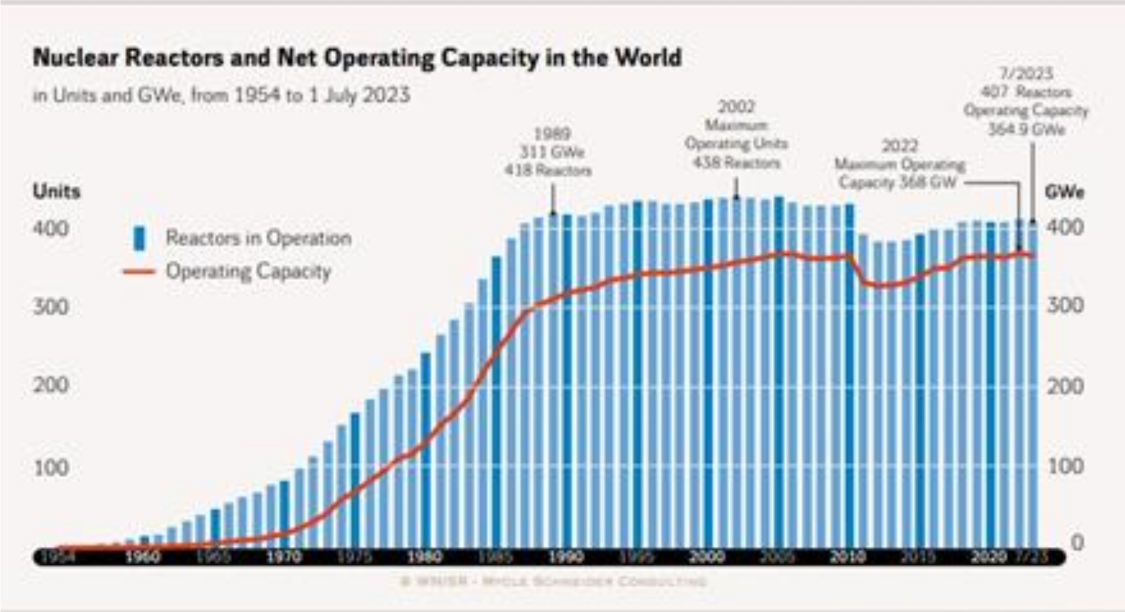
Every year, a group of international experts publishes the World Nuclear Industry Status Report. This report lists the most important nuclear developments worldwide. The most important conclusion in the 2023 edition: the decline in the share of nuclear power in global electricity production continues. There is no question of a nuclear renaissance. On the contrary, nuclear power is on its way out.

In 1996, nuclear power plants were producing at their maximum. At 17.5%, the share of nuclear power was at its highest worldwide in that year.



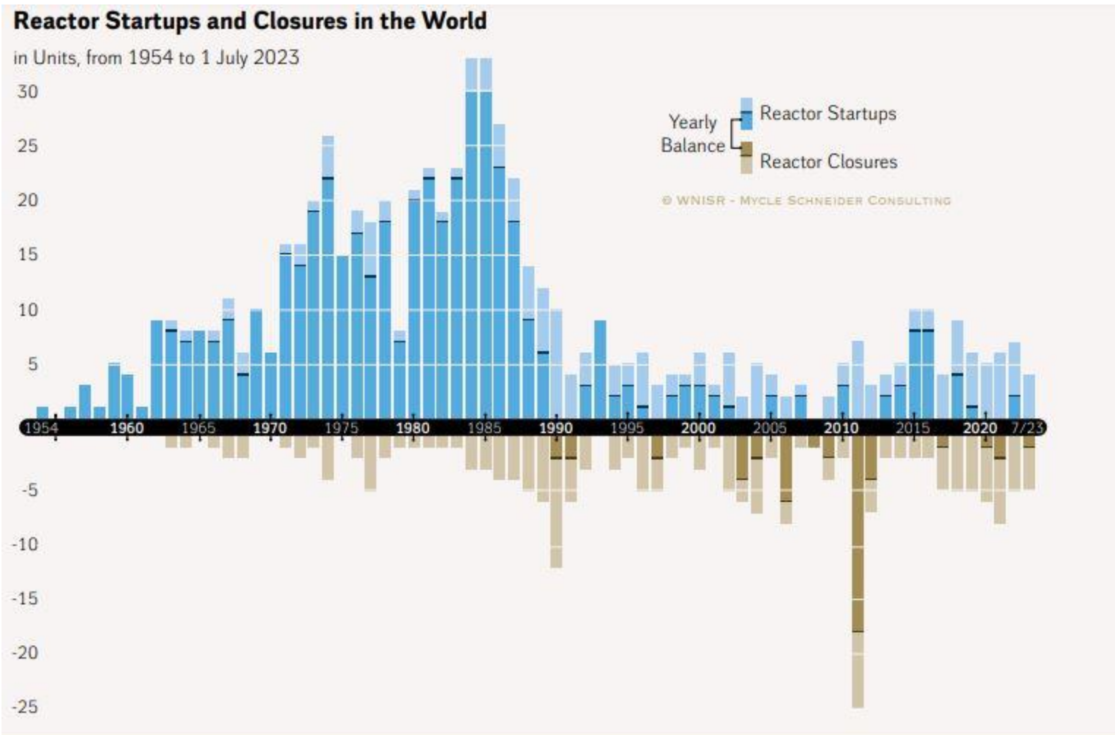
Meanwhile, the share of nuclear power has fallen to 9.2%. The big question, of course, is why. The most important thing is that the number of working nuclear power plants remains the same, while gradually more and more electricity is used in the world.

Figure 6 - World Nuclear Reactor Fleet, 1954-mid-2023



Sources: WNISR, with IAEA-PRIS, 2023

As of 2017, the number of nuclear power plants remains stuck at just over 400. It is true that new nuclear power plants are being connected, but about as many are being disconnected. This can be clearly seen in the balance sheet below.



Sources: WNISR, with IAEA-PRIS, 2023

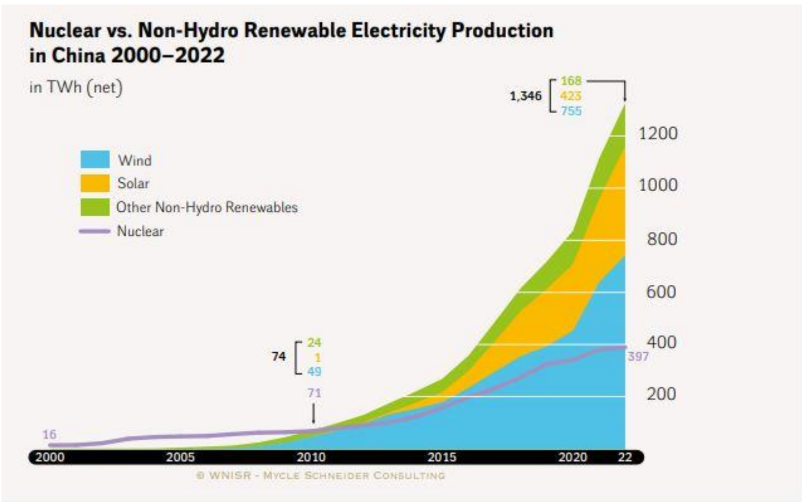
From 2017 onwards, the blue line (new nuclear power plants) and the brown line (closures) are in balance.

Major National Developments in 2022

- Belgium. One reactor was closed in September 2022, and another one in January 2023. Three of the remaining five units are to close by 2025, while operation of the two most recent ones is to be extended until 2035.
- France. Nuclear generation dropped below the level of 1990. Compared to 2010, output plunged by 129 TWh, much more than the 100 TWh Germany lost in nuclear production due to its phaseout policy over the same period. For the first time since 1980, France turned into a net importer of electricity. Threatened by bankruptcy over record losses and unprecedented net debt levels (US$70 billion as of mid-2023), the utility company EDF was renationalized.
- Germany. The three last operating reactors were closed on 15 April 2023, twelve years after the definitive phaseout policy was decided in 2011.
- South Korea. State-owned utility KEPCO filed a record loss of US$$_{2022}$25 billion with net debt rising by 32 percent to an unparalleled US$$_{2022}$149 billion.
- United Kingdom. Only nine units remain operating. The cost estimate for two reactors under construction at Hinkley Point C has reached US$$_{2021}$44 billion in February 2023, with first grid connection delayed to June 2027.
- United States. Nuclear share of commercial electricity generation declined to 18.2 percent, its lowest level in 25 years. After 10 years of construction, the first of two new reactors at Plant Vogtle was connected to the grid in April 2023. Cost estimates for the two units exceed US$35 billion.

China

There is still a major misconception about China. The persistent perception continues to circulate that nuclear power plants in China are constantly being connected to the grid. But what is happening there is that the share of renewable energy is increasing drastically.

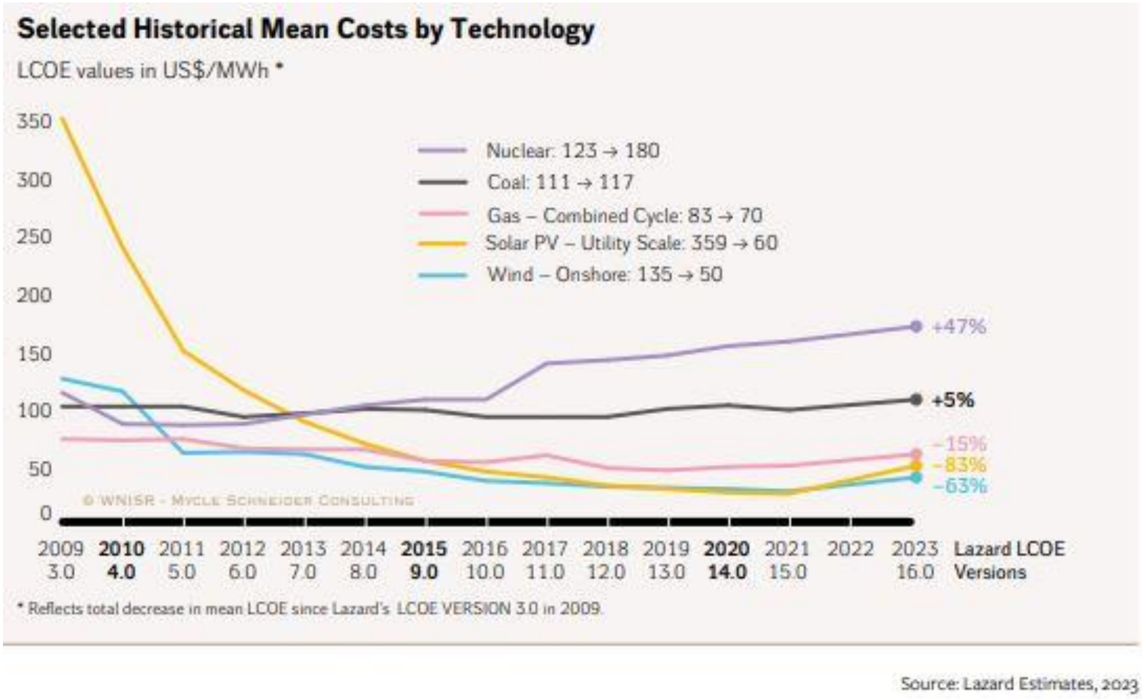


Source: Energy Institute, 2023

The production of nuclear power is steadily increasing, but the growth of solar and wind is particularly spectacular. This trend is not only seen in China. Globally, the amount of investment in renewable sources is significantly higher than the amount of investment in new nuclear power plants.

Cost

Not only in absolute production, but also in economic terms, renewable energy sources continue to outperform nuclear power. Cost estimates for solar energy fell by 83 percent, wind by 63 percent, while the cost of nuclear power has increased by 47 percent in the last fourteen years. It should be mentioned that due to higher costs and inflation, solar and wind have also risen in price in recent years.



Small Modular Reactors

Although virtually no small nuclear power plants (SMRs) have been built, the topic continues to make headlines. There are dozens of designs, and media and governments write highly of the possibilities. In 2023, the Nuclear Energy Agency released an SMR dashboard , claiming that there has been "substantial progress toward SMR deployment and commercialization" and "much of this progress has occurred in the last two years."

In practice, two designs have come into production in the past two years: one in China and two floating reactors on ships in Russia. Incidentally, the latter two have load factors of 34 and 22% – which indicates that there are still major problems in development. This became very clear a few weeks ago when NuScale, a company in the US that has been working on the development of SMRs since 2007 (!), had to pull the plug on its flagship product. Financial problems were the deciding factor.

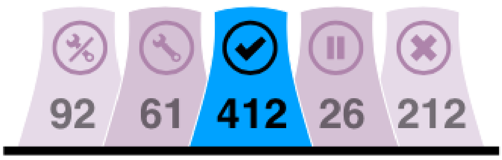
Renewable Energies Orders of Magnitude Ahead of Nuclear Power

- In 2022, total investment in non-hydro renewable electricity capacity reached a new record of US$495 billion (+35 percent), 14 times the reported global investment decisions for the construction of nuclear power plants. Wind and solar facilities alone generated 28 percent more electricity than nuclear plants and reached a 11.7 percent share of electricity generation, with nuclear shrinking to 9.2 percent.
- In China, solar PV produced a total of 423 TWh of electricity in 2022, for the first time overtaking nuclear power that generated 397 TWh. In the European Union, solar and wind plants together produced 624 TWh, for the first time exceeding not only nuclear energy (613 TWh) but also natural gas (557 TWh) and coal generation (447 TWh), while all renewable sources accounted for over 38 percent of the E.U.'s electricity production. In India, wind and solar plants together produced 3.7 times more power than nuclear reactors in 2022 Wind has outpaced nuclear in power generation since 2016. Solar passed nuclear generation in 2019.

The report shows that the nuclear renaissance is not happening: the big change is in the increase in solar and wind, while the share of nuclear energy is decreasing. The entire report can be read on the site of the **World Nuclear Report.**

Gerard Brinkman/Erik Plakman,
WISE Netherlands

World Nuclear Power Status



Number of Reactors

Source: https://www.worldnuclearreport.org

Compared to Nuclear Monitor 910, the number of reactors which are under construction has increased from 60 to 61. The new reactor is the fourth and final Barakah unit located in the Al Dhafra Region of Abu Dhabi. On 23 November, the UAE's nuclear regulator - the Federal Authority for Nuclear Regulation - issued an operating licence to Nawah Energy Company for commissioning and commercial operation of this unit.

The International Bank for Nuclear Infrastructure

The IBNI, International Bank for Nuclear Infrastructure, is a conceptual new multilateral international finance institution. This bank will be focused on supporting its member countries in developing new nuclear energy programs or expanding existing programs. IBNI supports large-scale investments in both current and commercially proven generation technologies, as well as tomorrow's Advances Reactors and Small Modular Reactors (SMR) and other emerging nuclear technologies. IBNI's core mission will be to support a sustainable net-zero world through the global expansion of nuclear energy. The bank believes that it is necessary for the world to achieve net zero greenhouse gas emissions by 2050 to reduce the most harmful impacts of global climate change and that the world's energy generation sector will play a dominant role in this. They state that to reach net-zero by 2050 in the most sustainable way, affordable, low carbon, safe and reliable nuclear energy is necessary and significant and that all nations of the world must have access to responsible and peaceful use of affordable, safe and reliable low-carbon nuclear energy.

Source: https://nuclearbank-io-sag.org